Damage and Restoration of the Electric Facilities in the Great Hanshin-Awaji Earthquake, Masaharu Kanayama, General Manager (System Engineering), Officer of Power System Engineering and Operation, The Kansai Electric Power Company, Incorporated

DAMAGE AND RESTORATION OF THE ELECTRIC FACILITIES IN THE GREAT HANSHIN– AWAJI EARTHQUAKE

by

Masaharu Kanayama

General Manager (System Engineering)

Office of Power System Engineering and Operation,

The Kansai Electric Power Co., Inc.

This paper summarizes the effects that the Great Hanshin-Awaji earthquake had on the power systems of the Kansai Electric Power Company (KEPCO). The disaster affected fossil-fired power generation plants, transmission lines, substations and distribution lines, and this led to the outage of 2,836 MW of power. However, services and facilities were restored relatively quickly. The key elements of this operation are described below. Thanks to its robust and flexible system configuration, KEPCO's power supply system was able to maintain its synthetic function even after such a large earthquake. Following an analysis of the damage sustained by our facilities, we have concluded that no significant change to the current seismic design criteria is necessary. However, the existing facilities have to be carefully checked, and steps taken to reinforce where necessary any areas of potential weakness.

1. Introduction

The earthquake, whose epicenter was in the northern part of the island of Awaji, occurred at 5:46 AM on Tuesday, January 17, 1995. It destroyed over 430,000 houses and other buildings and took the lives of more than 6,300 people. The earthquake measured 7.2 on the Richter scale, and was the largest recorded in the suburban area around metropolitan areas since the war, exceeding the magnitude of the 1948 Fukui Earthquake (7.1). Figure 1 shows the acceleration rate recorded at the Shinkobe Substation. The record of seismic intensity measured at surface level during this earthquake shows that the maximum acceleration exceeded 0.8G, and was approximately 1 m per second 2 (square second), one of the highest levels of intensity ever observed in Japan. As can be seen from Figure 2, which illustrates a spectrum of representative acceleration responses to the earthquake, this disaster produced a smaller degree of sway in buildings with a natural period of approximately 0.3 second than the earthquakes in Los Angeles (M = 6.6) in 1994 and off the coast of Kushiro (M = 7.8) in 1993. It, however, produced greater degrees of sway in buildings with a natural period of 0.8 - 2 seconds than these latter earthquakes. The latter natural period is known to be equivalent to that of medium-rise buildings of around 10 stories and that of a 200-meter-long bridge. Electrical facilities with a similar natural period of 0.8 - 2 seconds, such as disconnectors and arresters, suffered serious damage, such as breakage and collapse, caused by resonance. Table 1 compares the damage sustained by power systems with that caused by recent major earthquakes.

2. Damage to the Power System

The earthquake damaged KEPCO's fossil-fired power generation plants, substations, transmission and distribution lines and communications systems. The extent of this damage can be seen from Table 2 and Figure 3.

2.1 Fossil-fired Power Generation Plants

At two power stations, the earthquake caused the exposure and cracking of pre-cast concrete piles of oil tanks and the cracked and separated oil embankment, as the result of uneven settlement caused by earth liquefaction. At one power plant, the water tank was tilted by uneven settlement accompanied by the liquefaction of subsoil under the tank. However, damage such as oil spillage was not caused at any of these power plants.

2.2 Substations

Damage was sustained by 181 facilities in 50 substations, while the destruction of major facilities caused outages at 65 facilities in 17 substations. These outages were attributable to the slippage of transformers caused by tensile fractures in anchor bolts that fixed transformers to their foundation, oil leakage caused by displacement of the bottom of bushings of old-model of oil circuit breakers slid on the gaskets, or destruction of insulators of disconnectors.

2.3 Overhead Transmission Lines

Twenty steel towers were damaged, and one of these collapsed. The tower in question was of unusual construction, known as a hillside structure. Because the stances at the lowest levels are directly connected with a member material on a slope, the degree of flexibility afforded against unequal displacement is less than that to be found in the conventional Bleich structure. The remaining 19 towers sustained minor damage such as the destruction of component and this did not cause any outage.

2.4 Underground Transmission Lines

Damage leading to outages occurred in 3 lines and 20 phases, which featured a special conduit structure. This structure was so rigid that it could not cope with ground movements, and this caused cable damage.

2.5 Overhead Distribution Lines

Damage to overhead distribution lines, which led to outages, included the breakage and collapse of 3,300 the distribution poles; the breakage and burning down of about 2,700 spans of electric cable; and breakage and burning down of about 1,200 bushings of transformers. Approximately 80% of the breakage and collapse of the distribution poles was secondary damage following the collapse of surrounding buildings. Most of the damage to cables was caused by the spread of fire and the breakage of the distribution poles. About 80% of damage to the pole transformers was caused by fire, although relatively little damage was sustained by components such as bushing. No transformers fell from their supporting standards.

2.6 Underground Distribution Lines

Outages were caused in 197 underground distribution lines, and of these about 30% were due to the destruction of supply lines caused by damaged customers' homes and other buildings. Other outages were caused by the collapse of the cable riser poles, as well as of conduits and manholes. This kind of damage occurred more frequently in areas subjected to a seismic intensity of 7 on the Richter scale and to liquefaction.

More overhead distribution lines were damaged by adjacent buildings than were underground facilities. Underground distribution lines, in which cables are buried in conduits, suffered less damage leading to outage, although they sustained a large amount of minor damage which did not lead to outage.

2.7 Communications Systems

The collapse of the distribution poles, together with fires in surrounding areas, caused the breakage or burning down of 171 spans of communications cable in Kobe City and some other areas. While there was no damage leading to the outage of multiplex radio communication systems, 12 systems were momentarily disconnected (communications were temporarily interrupted) just after the earthquake occurred. The damage to KEPCO's Kobe Branch building made it necessary to move elsewhere the communications systems installed there. However, since the multiplex radio communication facilities, which play a vital role in the communications network that ensures the security of electricity supply, were intact, the in-house communications needed to ensure the progress of restoration work were maintained. Even under the conditions of emergency immediately after the earthquake, information about the electricity supply situation was available, and the lending or borrowing of necessary by power companies could be transacted without any difficulty.

3. Initial Activites

Electric power companies subject all levels of their supply systems, from generation, transmission and transformation to the feeding of electricity into the distribution network, to 24-hour monitoring and control. When an accident occurs, responsible staff is given authority to take measures appropriate to each situation, such as emergency operations, in order to minimize the extent of power failure and to restore supplies as rapidly as possible.

After this earthquake happened, responsible staff immediately began working to restore the substation to which they were assigned. Specifically, control centers which control substations and manned substations, conducted detailed examinations of the damage that had been caused, and repaired what they thought they could rectify by themselves by using remote control. Other damage was reported to the load dispatching center which oversees the whole electricity supply system, so that instructions for the restoration of service could be issued from there. The office examined ways and means of resuming supplies by shutting down damaged transmission systems and switching-in others which were intact. It also issued instructions for the operation of equipment to control centers and manned substations. These latter then proceeded to restore affected substations to service either by the remote control of equipment or by implementing procedures on site.

This speedy restoration of service made it possible to reduce the level of outage from 2,836 MW at 5:46 AM, immediately after the earthquake struck, to 1,245 MW by 7:30 AM and to 487 MW at noon on the same day. From 18 January, efforts were concentrated mainly on restoring distribution lines. By mobilizing 4,701 people from the distribution department, other power companies and affiliated organizations, KEPCO was able to provide full temporary supplies of power to all customers capable of receiving it by 3:00 PM on 23 January. Figure 4 shows how the power supply outage situation developed.

4. Emergency Restoration Activities

As soon as the earthquake occurred, KEPCO devised and implemented plans to deploy their personnel into the stricken areas, and committed increasing numbers of people to restoration work as this progressed. During the period of emergency restoration between 17 and 23 January, 4,701 people were mobilized from our distribution department, from other power companies and from affiliated companies. This number rose to 6,100 on a peak day. Materials used in the restoration work included items that had been set aside for such emergencies and for general construction work, as well as insulators, hardware for connecting wires and cables, and the power generator vehicles offered by other power companies. Fortunately, the material stored by KEPCO was sufficient to enable us to overcome the problem of outage during the emergency period. Supporting companies, with experience of providing support after typhoons and other disasters, dispatched self-sufficient support groups, equipped with fuel for the power generator vehicles, experienced driving staff and sufficient supplies of food and daily necessities to sustain themselves.

From 17 January onwards, items such as food, drink, clothing and bedclothes for the staff engaged in restoration work were brought to them from Head Office and our Himeji Branch.

5. PR Activities

Between 17 January and 3 February, KEPCO issued between 40 and 120 public announcement messages every day (576 in total), mainly through the medium of radio programs, to people living in the stricken areas, giving information about the location of power failures, the ongoing restoration work and the planned schedule of restoration, as well as warnings about the risks of electric shock and the leakage of electricity through spot radio message. In addition to supplying information in news programs, as necessary, KEPCO supported the appearance of its employees on TV and radio programs, during which they told the public directly about the latest power supply conditions and recommended what they should do to prevent accidents.

6. Emergency Transmission

6.1 Emergency Methods of Transmission to the Distribution lines

Emergency restoration work was carried out mainly on the overhead transmission lines, using temporary facilities which were relatively easy to set up. In order to restore transmissions as quickly as possible, the volume of work was minimized by excluding transmissions from those areas in which levels of destruction were severe, by disconnecting the high-voltage lines, and connecting to the lines in areas whose systems were intact, through by-pass cables and temporary lines. The power generator vehicles were used to provide emergency supplies of electricity to essential services, such as government organizations, police stations, fire stations and general hospitals, whose addresses were on record at KEPCO.

Electricity was supplied to an increasingly large area by restoring distribution facilities promptly, and by relocating generator vehicles from restored areas to others. During the emergency restoration period, electricity was transmitted to individual customers in the severely stricken areas with the utmost care, in order to prevent the occurrence of a secondary disaster. The following operational principles were established.

(1) Measures to be taken following restoration of distribution lines

(a) Transmissions to high-voltage (6.6 kV) users via high-voltage lines were to be carried out through service entrance switches, and to low-voltage (100V,200V) users through a primary switch of a transformer mounted on an electricity pole.

(b) Transmissions through low-voltage lines to customers living in wrecked houses, or to unoccupied premises, were postponed.

(2) Measures taken when transmissions to customers were to be restored

(a) Transmissions to high-voltage users were to be resumed only after due discussion with the customers' senior engineers.

(b) Transmissions to low-voltage users were to be resumed only after the safety of customers' facilities had been confirmed.

6.2 Examination of Disaster Prevention Measures

According to information published by Kobe Municipal Fire Station on 14 April, 1955, 175 fires occurred in Kobe City during the 10 days following the earthquake. Of these, 44 were reported as being associated with electricity.

However, in view of the facts that the transmission of electricity was suspended over a wide area when the earthquake happened, and that transmissions did not resume until after 8:00 AM, no fire during the initial period, especially one affecting a wide area immediately after the earthquake, could be attributable to electricity. Most of the fires associated with electricity were caused by burning carpets and by combustible floor material ignited by household electric appliances, such as fallen electric stoves or exposed tropical fish tank water heaters.

The disaster-prevention measures which should be taken by customers, electrical appliance manufacturers and power companies against a potential earthquake may be summarized as follows:

(1) Measures to be taken by customers

* Disconnect the contact breaker, installed in each house, and turn off all heating appliances before leaving home.

* Examine the condition of appliances, and check for gas leaks before using electricity.

(2) Measures to be taken by electric appliance makers

* Fit devices which turn off the electricity, and prevent it from being easily turned on again, when appliances fall over.

(3) Measures to be taken by power companies

* Issue extensive publicity describing the various precautions which consumers should take when resuming the use of electrical appliances.

7. Restoration Activities

In order to ensure that all facilities were fully restored, the work that needed to be done to ensure completion was carried out prior to the summer peak season, and all work involving mechanical reinforcement prior to the rainy and typhoon seasons.

This made sure that KEPCO would be able to cope successfully with the rainy and typhoon seasons, and to achieve without difficulty a record supply of 31,520 MW, 130 MW more than the previous record supply figure achieved last year, on a peak day in summer. The improvement work, which still continues according to plan, is expected to restore most of the stricken facilities by the end of March, 1996.

8. Evaluation of the Earthquake-Resisting Capacity of Electric Facilities

Immediately after the earthquake, outages occurred as a result of the destruction of facilities in 189 substations. By 8:00 AM the following day, however, all substations had been repaired sufficiently to enable them to supply electricity. The power system are configured, by the use of multi-level and multi-route equipment, to prevent serious outages under emergency conditions. During this earthquake, the switching from damaged systems to intact ones permitted the emergency transmission of electricity to be completed at an early stage. We believe that the existing electricity supply system was already capable of coping with seismic vibrations of such high intensity.

Equipment at the Shin-Kobe and Itami Substations did sustain damage, but this was not serious enough to cause them to cease functioning. Most of the damage was sustained by older facilities, which had been installed prior to the introduction in 1980 of the current seismic design criteria, which were based on the lessons learned from the earthquake off the coast of Miyagi in 1978. No serious damage was caused to the newer facilities which were built in conformity with the current criteria. The design criteria for electrical facilities take account of lessons learned from past major natural disasters, such as earthquakes and typhoons. Changes to these design criteria are shown in Table 3. Table 4 illustrates the relationship between the age of distributing substations in the area subjected to a seismic intensity of 7 and the extent of the damage suffered. No damage was sustained by the substations built in conformity with current design criteria.

Evaluations of the current seismic design criteria and views on possible future amendments to them have been examined at national government level. An outline of this examination is given below.

The principles of ensuring adequate resistance to earthquakes by taking account of this particular disaster are shown in the Basic Anti-Disaster Plan issued by the National Land Agency (determined in July 1995 at a meeting of the Central Disaster Prevention Council). The Council for Studying Anti-earthquake Measures for Electrical Facilities, an advisory body to the Minister of Resources and the Energy Agency, conducted an investigation into the Basic Anti-Disaster Plan (March 13 - November 24, 1995), and defined the following categories.

(1) Earthquake-resistance category I (dams, LNG tanks and oil tanks)

* General levels of earthquake movement must not cause any serious disturbance of the operation of any facility , and high-level earthquake movement must not cause serious damage to lives.

(2) Earthquake-resistance Category II (power generation facilities, transmission lines, substations and distribution lines other than those defined in Category I, load dispatching centers and electrical security communications systems)

* General levels of earthquake movement must not cause serious disturbance of the operation of any facility, and the overall operation of the power supply system must be maintained by ensuring the availability of alternatives or of multiple replaceable functions, in order to prevent the risk of significant (long-term and wide-ranging) outages even in the event of high-level earthquake movements.

The report on the investigation recommended that, with regard to underground lines, in respect of which no seismic design criteria are specified, the parameters applicable to designs using flexible joints and conduits should be established, with any necessary modifications and improvements, as seismic design criteria. With regard to other facilities, it evaluates that the current seismic design criteria, which were established based on lessons learned from previous earthquakes can suitably specify earthquake resistance which each electricity facility should equip, and recommended that those facilities which were built on the basis of old criteria, and which can be expected to be the cause of serious supply outages, as well as of damage elsewhere, should be brought into conformity with current criteria.

9. Future Plans

Electricity companies intend to implement as planned all measures that may be required to bring existing facilities into conformity with the current seismic design criteria, and to ensure their safety in the event of an earthquake.

10. Key Reference

Resources and the Energy Agency : Anti-earthquake Measures for Electrical Facilities, 1996 (in Japanese).

Table 1 Damages sustained by major earthquakes.

		Off-Tokachi	Off-Miyagi	The Hanshin Awaji
Date		May. 16, 1968	Jun. 12, 1978	Jan. 17, 1995
Magnitude		M7.9	M7.4	M7.2
Social Damage	Fatalities and Missing	52	28	6. 308
	Completely & Partially Destroyed buildings	3,677	6,757	436. 416
Interruption of Electricity Supply	Outage	1,140 MW	1,130 MW (about 0.68 Million Customers)	2,836 MW (about 2.6 Million Customers)
	Restoration	May 18 (for 3 Days)	June 14 (for 3 Days)	January 23 (for 7 Days)
Damage to Electric Power Facilities	Overhead Transmission Line	(579 incidents)	32 Transmission Lines	23 Transmission Lines (62 incidents)
	Underground Transmission Line	3 Transmission Lines (10 incidents)	No Damage	102 Transmission Lines (905 incidents)
	Substation	—— (138 incidents)	18 Substations (91 incidents)	50 Substations (181 incidents)

Table 2 Damages sustained by power generation facilities.

Facilities	Unit	Number of damages: Major electric structures	Others	Total	Total number in KEPCO
Nuclear power plant	Units	0	0	0	3
Hydroelectric power plant	Units	0	0	0	141
Fossil-fueled power plant	Units	5	5	10	21
Substation	Units	17	33	50	861
Overhead transmissionline	lines	11	12	23	1. 065
Underground transmissionline	lines	3	99	102	1. 217
Distribution line (※)	lines	660	——	660	13. 490
Communication facilities	lines	——	76	76	4. 048

(※) Including 22 and 33kV facilities.

Table 3 History of design criteria for electric facilities.

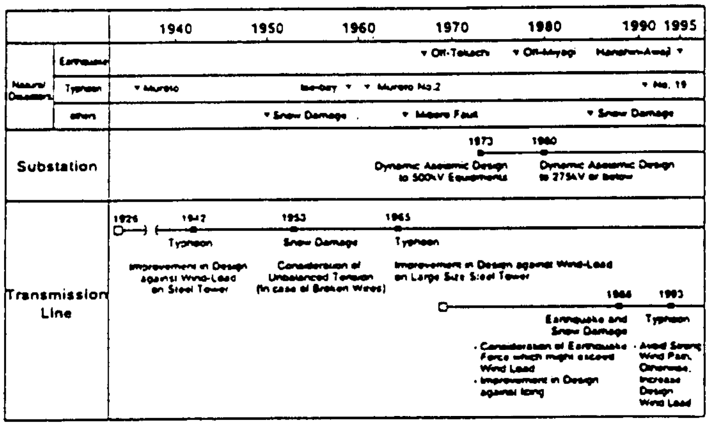


Table 4 Ratio of Damaged Substation in the Area of Seismic Intensity of "7".

	Year of Constructions (*): Before 1955	1955~1964	1965~1974	After 1975	Total
Damaged	7	7	0	0	14
Not Damaged	0	6	6	3	15
Ratio of Damaged Substation	100%	64%	0%	0%	48%

(*) If main equipment was refurbished, the year of refurbishment is indicated.

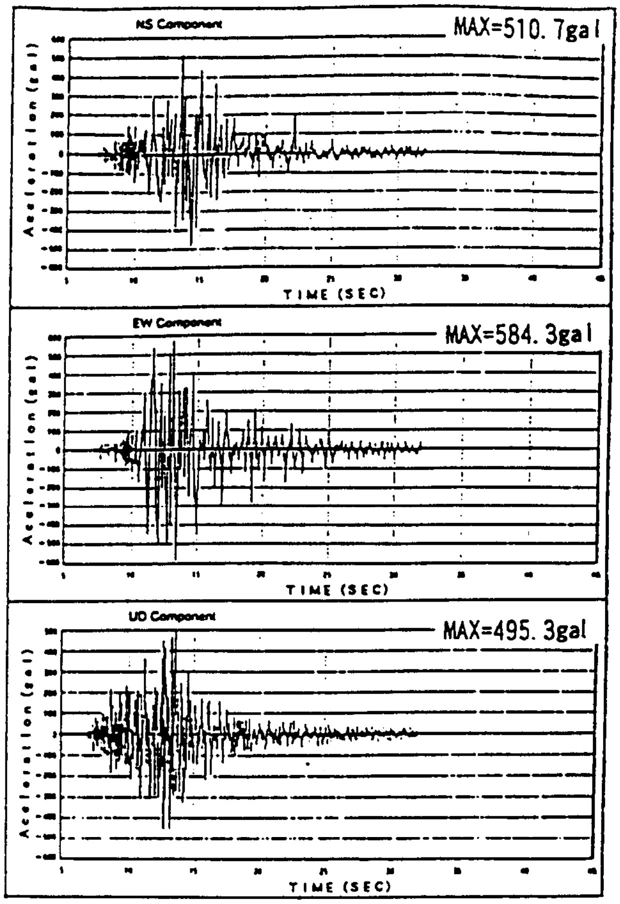


Figure 1 Acceleration observed at Shin-kobe substation.

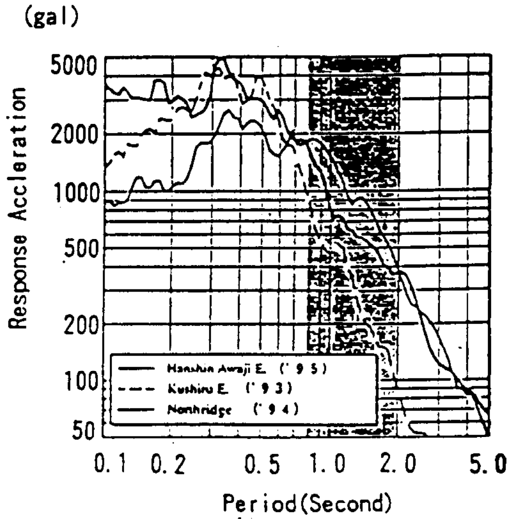
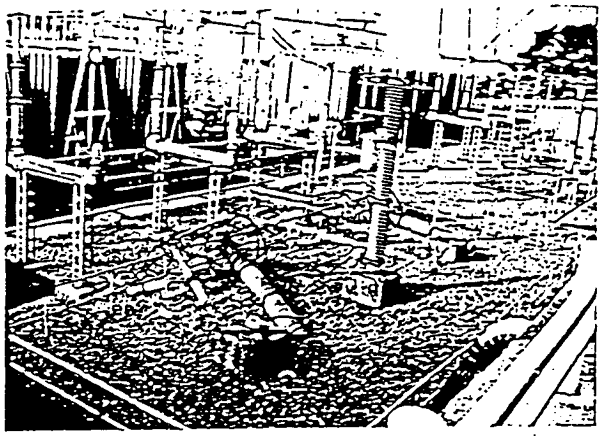
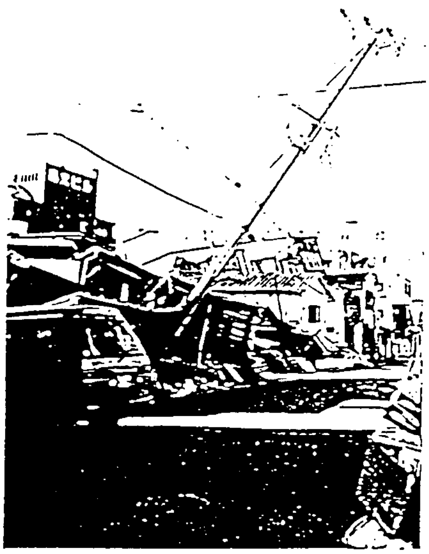


Figure 2 Maximum horizontal Acceleration Distribution. (Obayashi Corp.)



(a) Damaged Arresters and Disconnectors in a Substation.



(b) A leaned distribution pole due to the collapse of a building.

(c) Destroyed bridges for underground wire.

Figure 3 Damages to electric facilities

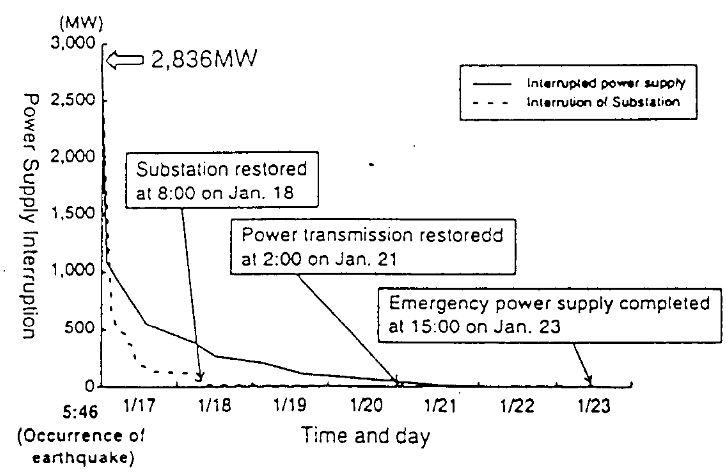


Figure 4 Progress in power supply interruption.